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TRAINING EXTENSION COURSE COST AND TRAINING EFFECTIVENESS ANALYSIS METHODOLOGY

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This report addresses the development of a methodology for Training Extension Course (TEC) Cost Training Effectiveness Analysis (CTEA), where effectiveness is a function of unit performance as measured by the Army Training and Evaluation Program (ARTEP). This report deals specifically with the theoretical development of the methodology.

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FOREWORD

This task report is one of several provided by the Mellonics Systems Development Division of Litton Systems, Inc., to the Army Research Institute for the Behavioral and Social Sciences (ARI) under Contract Number DAHC 19-77-C-0011.

Under the contract, a part of the Mellonics effort concerns support to the ARI evaluation of the utilization, acceptance, costs and effectiveness of the Army Training Extension Course (TEC) Program. Related earlier reports focused on the cost and training effectiveness of TEC where effectiveness was a function of individual performances on selected hands-on performance tests, and the relation of TEC usage to individuals performances on their SQT. Results showed TEC effective in training individuals and a positive relationship between TEC usage and SQT scores.

The first TEC report[1] in this current series documents the conduct and findings of a training, cost and effectiveness literature search and review of selected literature. It serves as the introduction to other reports in this series. The second report[2] provides guidance for the collection of individual and unit training data necessary to support the TEC Cost Training Effectiveness Analysis (CTEA) Methodology. This report addresses the development of a TEC CTEA Methodology, where effectiveness is a function of unit performance as measured by the Army Training and Evaluation Program (ARTEP) evaluation. This report is the theoretical development of the Methodology. A planned subsequent report will deal with the practical application of the Methodology.

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[1] Sassone, P. G. Literature Review - Cost and Training Effectiveness. Litton-Mellonics, Training Extension Course Research Task Report: July 1978.

[2] Bercos, J. Extension of Training Extension Course Cost and Training Effectiveness Analysis Data Collection. Litton-Mellonics, Training Extension Course Research Task Report: June 1979.

TRAINING EXTENSION COURSE COST AND TRAINING EFFECTIVENESS ANALYSIS METHODOLOGY

BRIEF

Requirement:

To develop a Cost and Training Effectiveness Analysis (CTEA) Methodology that will identify the contributions of Training Extension Course (TEC) training to a unit performance as measured by the Army Training and Evaluation Program.

Procedure and Findings:

The development of the Methodology required four areas of specification. First, a measure of unit effectiveness was assumed to be derivable from the pass/fail (satisfactory/unsatisfactory) scoring criteria currently in use. Secondly, the assumption was made that costs of field, garrison, and TEC training can be determined. Thirdly, the resource allocation model was developed from which can be inferred the economic value of TEC. The effectiveness production function assumes some specifiable relationship between inputs and outputs of the training process which operates under specific budget constraints. Lastly, the use of the valuation methodology in a present value analysis to derive an ultimate dollar value of TEC was outlined.

Utilization:

This report describes a CTEA Methodology which integrates implicit knowledge of the training process and training budget constraints to evaluate the effectiveness of TEC training. The unit is the object of the analysis which is evaluated by means of ARTEP procedures. Since TEC usage can change both effectiveness and costs, the valuation methodology was developed from a cost-benefit point of view. However, this valuation methodology can be applied to any training program which serves a complementary, rather than as a substitute, training program.

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TRAINING EXTENSION COURSE (TEC) COST AND TRAINING EFFECTIVENESS ANALYSIS (CTEA) METHODOLOGY

INTRODUCTION

THE TRAINING EXTENSION COURSE (TEC) PROGRAM

TEC is a program that has been designed to put into the hands of trainers, both in units and in institutions, high quality performance-oriented multimedia training packages. It is designed to provide soldiers with immediate access to self-paced instruction especially designed to assist them in acquiring and maintaining skills critical to their performance in combat. TEC lessons are designed for use on an individual basis; however, they may be used by small groups, under the supervision of an NCO.

TEC RELATED RESEARCH

The advent of the TEC program inaugurated a multi-faceted TEC research effort conducted under the sponsorship of the U. S. Army Training Support Center (USATSC) by the U. S. Army Research Institute for the Behavioral and Social Sciences (ARI) and the Mellonics Systems Development Division of Litton Systems, Inc. The research comprises investigations concerning current and projected usage of TEC in the Active and Reserve Components, training effectiveness and retention of TEC instruction, current and projected costs of the TEC program, cost-effectiveness of TEC, and the development of a TEC Manager's Guidebook.

- o The effectiveness and retention[3] investigation evaluated TEC lessons relative to conventional instruction in the Active and Reserve Components. The experiments included five subject areas, one common to all combat arms soldiers and four specific to each of the four combat arms. The investigation determined that, averaged across the five subject areas, the TEC trained soldiers performed better than the conventionally trained soldiers on both the initial and retention (8 to 9 weeks after the initial) hands-on performance tests.

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[3]Holmgren, J. E., Hilligoss, R. E., Swezey, R. W., and Eakins, R. C. The Training Effectiveness and Retention of TEC Instruction in the Combat Arms. U. S. Army Research Institute for the Behavioral and Social Sciences, Research Report Draft: May 1978.

- An effectiveness and retention related investigation[4] concerned the relationship of performance on the Skill Qualification Test (SQT) and the amount of TEC use. The investigation was based on TEC usage data (TEC usage investigation above) and SQT data obtained from USATSC for the same personnel (3 Armor and 3 Infantry battalions) to whom the usage data applied. Correlation analyses showed a consistent positive relationship between the use of TEC lessons and performances on the relevant SQT.

- The investigation of TEC program costs[5] produced cost information for use in a TEC cost and Training Effectiveness Analysis (CTEA). The information was developed in terms of sunk costs (monies expended or obligated in the period prior to FY 1978) and future costs (estimates of annual costs to be incurred in continuing a given TEC program during the period FY 1978 through FY 1987). Both costs, sunk and future, include contract costs and other government costs. From the sunk costs and other information, estimates were developed for the cost of TEC to a battalion.

- An adjunct TEC cost investigation[6] concerned cost savings or cost avoidance to the U. S. Army resulting from the use of already available TEC materials to replace or supplement conventional instruction at the TRADOC Branch Schools. Data for FY 1977 collected from the TRADOC schools showed real and potential annual cost savings from the direct use of TEC materials in instructional training and cost avoidance (no need to develop materials) from TEC substitution for conventional instruction in new or self-paced training.

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[4] Strasel, H. C., Holmgren, J. E., Bercos, J., Shafer, J. C., and Eakins, R. C. <u>Training Extension Courses (TEC): Cost and Training Effectiveness</u>. U. S. Army Research Institute for the Behavioral and Social Sciences, Research Report Draft, November 1977.

[5] Ibid.

[6] Ibid.

- A second adjunct cost investigation concerned the quantification (and expression in dollars) of TEC benefits. The benefits were estimated as potential savings of training resources (time and ammunition) resulting from TEC trained individuals' better performance on selected tasks than conventionally trained individuals for a period of combat/intensive training. The investigation showed the potential is real to achieve a given level of soldier proficiency with a reduced period of combat/intensive training or to exceed the given level of soldier proficiency in the normal period.

- The cost-effectiveness analyses[7] integrated the data and results from the above outlined research, and also used the data and results to assess the relative worth of TEC. For the relative worth analysis, an estimated cost of a TEC impression (a single use of a TEC lesson by one individual) was developed, as was a model to estimate individual soldier proficiency in relation to training on specific tasks conventionally and with TEC. The relative worth analysis indicated that, at the current usage level, TEC training is equivalently cost-effective as conventional training, and that at higher usage levels, TEC can be more cost effective.

The research outlined above mainly addressed the cost and training effectiveness of TEC instruction relative to the individual combat arms soldier. Obviously, the same or extended analyses are needed for units. In this connection, the USATSC has defined a requirement for Cost and Training Effectiveness Analysis (CTEA) of TEC in relation to unit performance as demonstrated in an Army Training and Evaluation Program (ARTEP) evaluation as discussed in the preceding TEC report. Because of TEC's unique complementary role, it does not fit the usual training program mold, and analytical techniques available in current training literature are not completely suitable for a TEC evaluation. General guidance for a TEC CTEA is available; nonetheless, it appears a TEC-specific evaluation methodology must be developed.

PURPOSE

The purpose of this research is to develop a TEC CTEA Methodology for determining the value of TEC in terms of unit performance on the ARTEP evaluation.

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[7]Ibid

APPROACH

General. The overall research was envisioned as an extension of the CY77 TEC CTEA (outlined above) to include investigation of the relations among TEC use and both unit and individual training costs and effectiveness. The research would involve development of a TEC CTEA methodology, data collection, and application of the methodology to an analysis of the data.

A data collection plan - including the development of forms, instructions for their use, determination of the types and numbers of units required to provide data, and procedures for the implementation of data collection - has been drawn. Commencement of data collection, however, pends the identification of specific units to participate. Accordingly, the application of the methodology to an analysis of empirical data is pending. As an interim offset, therefore, the methodology was applied using hypothetical data.

The development of the methodology for determining the value of TEC commenced with a review of literature[8] concerning the current state of the art in CTEA methods. Although the review disclosed no readily available CTEA methodology suitable for TEC, it provided an essential overview of CTEA requirements.

TEC CTEA Requirements. CTEA in general must involve a comparison of the effectiveness and costs of alternative training systems. Since any decision regarding a modification of any part of the training system must be made in consideration of the effects of that modification on the effectiveness of the force structure, a CTEA must relate a (proposed or actual) change in the training system to its ultimate impact on combat effectiveness. This means the CTEA must be performance-oriented. It also means that any proposed alternatives must be compared with the baseline system, which is the best currently available training system. The comparison can be of three different types: equal costs, unequal effectiveness; equal effectiveness, unequal costs; or unequal costs and unequal effectiveness.

The TEC program is primarily a complementary, rather than a substitute, training program. That it, it does not substitute for a different training program (although it can be used, selectively, to substitute for parts of the existant training program). It is intended to be used in conjunction with other existing programs. This

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[8] Sassone, Literature Review - Cost and Training Effectiveness.

complementary nature is a critical point, because it serves as a basis for evaluating TEC as an addition to existing training programs.

Since TEC is intended neither as strictly a cost-substitute program to increase effectiveness at the same level of costs, nor as strictly an effectiveness-substitute program to decrease costs while maintaining effectiveness, the traditional cost-effectiveness approach to training program evaluation is not applicable. That is, it is not appropriate to evaluate TEC as though it were strictly intended to minimize costs while maintaining effectiveness or to maximize effectiveness while maintaining costs. Rather, it must be explicitly recognized that TEC could simultaneously change both effectiveness and costs. The issue then becomes: Is the change in effectiveness worth the change in costs? This question demands a cost-benefit[9], rather than a cost-effectiveness, point of view.

Accordingly, with account of the usual CTEA considerations[10] and a TEC CTEA's kinship to a cost-benefit analysis, five methodological requirements for a TEC CTEA were identified.

- the baseline training system must be identified and its parameters quantified.
- the training system inclusive of TEC must be defined and its parameters quantified.
- An input cost function must be developed which maps any training system configuration into its dollar cost.
- an approach must be devised which objectively translates changes in effectiveness into corresponding dollar values.

The development of a TEC evaluation methodology to meet the requirements is susceptive to the methods of microeconomics and welfare economies. The evaluation procedures are objective, and result in ultimate dollar valuation of the TEC training concept.

9The cost-benefit approach is sometimes adopted in private sector studies, but these benefits are estimated as increases in wages. This approach is clearly inappropriate for military applications.

10U.S. Army TRADOC Systems Analysis Activity. Cost and Training Effectiveness (CTEA) Handbook. White Sands Missile Range, New Mexico. Author, 1976.

Technical Approach. The approach adopted in the development of this CTEA methodology is an extension of a model and several concepts from economic theory. The model used here to guide the choice among various types of training and to assess the value of TEC is an extension of the microeconomic theory of the consumer. Basically, we substitute a training effectiveness production function for the traditional utility function, where the former has much the same mathematical structure as the latter. The key concepts enjoyed here in developing dollar values for the TEC program are the compensatory budget variation and the equivalent budget variation. These concepts are central to theoretical welfare economics, where they provide measures of the welfare effects of price changes on consumers. We extend these concepts to provide dollar measures of the value of training programs. The TEC CTEA methodology section report explains the model and concepts just mentioned.

ORGANIZATION OF THE REPORT

The report comprises three major sections:

- This introduction is the first section. It presents the background, states the objective, outlines the scope, and generally describes the overall approach of the investigative effort.

- The second section outlines the TEC CTEA methodology. It discusses the construction of effectiveness production functions and procedures to determine the cost of various types of training. This section discusses the basis of the methodology in economic theory, describes its adaption to an Army Training situation, explicates the development of the valuation part of the methodology, presents an algebraic example, and shows the use of the valuation methodology in a present value analysis to derive an ultimate dollar value of TEC.

- The last section summarizes the investigative effort and presents some further consideration.

TEC CTEA METHODOLOGY

The objectives of this section are to develop and explain a methodology which can be used to provide an objective economic evaluation of the TEC Program, and very likely, other military training programs as well. As mentioned above, the methodology is based on modern welfare economics, that branch of economics which deals with the normative evaluation of alternative economic states. The methodology involves four steps:

- Specification and estimation of an Effectiveness Production Function.
- Estimation of the "per unit" costs of the different types of training contributing to overall effectiveness, as well as determination of the magnitude of the training budget.
- Calculation of the current value of the TEC Program.
- Calculation of the present value of the TEC Program.

Each of these steps involves a number of (sometimes technically complex) substeps. The four steps are discussed in this section; however, Step 3, the Valuation Methodology, is the heart of the CTEA Methodology, and this section of the report deals primarily with the development of that step.

EFFECTIVENESS PRODUCTION FUNCTION

The first step of the methodology is to determine the effectiveness production function. A valid measure of unit combat effectiveness must exist in order to carry out the valuation methodology. It is assumed that a unit's performance on selected missions during the Army Training and Evaluation Program (ARTEP) evaluation accurately reflects the unit's capability to successfully perform these missions in combat. It is also assumed that reliable measures of effectiveness can be construed for each ARTEP mission; however, it is recognized that an adequate measure of effectiveness is not apparent from a normal ARTEP evaluation. The ARTEP evaluation results in units being judged satisfactory or unsatisfactory on selected missions. This gross measurement of unit performance lacks the sensitivity necessary to adequately discriminate among the various types of individual and collective training received by the unit. Accordingly, some procedure must be established to convert the ARTEP ratings of satisfactory/unsatisfactory to a numerical measure of effectiveness. Currently, a scale of zero to one is being utilized for the measure of effectiveness.

A precise measure of relative unit performance is further complicated by the subjective nature of ARTEP evaluation. Even though many standards appear to facilitate an objective evaluation (time, distance, numbers, etc.), most pass/fail decisions include considerations for visibility, climatic conditions, preceding unit activity, tactical situation, etc., as well as the individual perspective of the evaluation. Recognizing the inherent problems of obtaining reliable unit effectiveness data, experience has proven that competent evaluators, properly briefed, will provide valid data and a relatively consistent measure of unit effectiveness.

In addition to a precise measure of unit performance, there is a requirement to determine the contribution of various TEC lessons to unit performance. Current TEC lessons are designed to primarily teach individual tasks. This necessitates concentration on ARTEP tasks and standards, rather than overall mission performance.

The difference in ARTEP design will require that an effectiveness production function be constructed for each type of unit undergoing evaluation. Two procedures for measuring unit performance are suggested. Each ARTEP task or standard may be equated to a numerical effectiveness measure of zero to 10 points - a seven may be equal to a satisfactory performance while a higher number indicates something better than the performance standard (e.g. a five-minute standard completed in four minutes) and a number below seven would allow for some distinction among units judged unsatisfactory. The procedure used in the development of hypothetical data to exercise this model was to assign a numerical value to each standard or portion of a standard and the unit performance (output) for each task was derived from the number of satisfactory and unsatisfactory standards. The inputs to the function are obtained through the collection of individual personnel data (all personnel assigned to the unit undergoing evaluation) and the collection of detailed data which reflects all individual and collective training activities of the unit.

COST OF TRAINING

The second step of the methodology involves determining the costs of the different types of training contributing to overall unit effectiveness. It would be a simple task to determine the annual training budget for an Army Division; however, a squad's share of that budget for a specific period of instruction is not readily available.

For the development of this methodology, training was divided into three categories: TEC, garrison, and field. Data forms were developed to record all individual and collective training for an eight week period prior to the ARTEP evaluation. The collected data provides information concerning the time expenditure of all personnel by rank, the type and amount of training each individual has attended, the type of facility utilized, the type of vehicles used and mileage for each, and the type and amount of all ammunition. With the above data, using current cost information, the cost of each type of training was determined for use in the hypothetical data. This provides comparative costs for a given amount of TEC, garrison, and field training.

No absolute training budget constraint figure was used for the hypothetical units, but the budget constraint was treated as a variable and was a consideration in all cost computations.

ECONOMIC THEORIES

Before commencing a technical development of the methodology, it may be useful to briefly summarize the economic theories on which it is based, which are the theory of consumer behavior and the theory of economic welfare. The theory of consumer behavior attempts to explain the behavior of rational individuals in the context of a market. Individuals are faced with a large number of available goods, each with fixed price, and have a fixed and finite income with which to purchase some "market basket" of goods. The individual is assumed to possess a set of preferences over all possible market baskets. These preferences satisfy four axioms: greed, completeness, transitivity, and diminishing marginal rate of substitution. These axioms are the basis for the utility function, which is a convenient and analytically tractable representation of a consumer's preferences. The theory of economic welfare starts from the preceding theory and asks: under what circumstances (particularly regarding price and income changes) is the consumer made better or worse off? An answer to this question is formulated using the concepts of compensating and equivalent variations in income. At first blush, these economic theories seem to bear little relation to the problem of evaluating military training programs. Nonetheless, the areas are sufficiently formally parallel that the economic theories can be successfully adapted to the military context. In essence, the two different problem areas are found to have similar mathematical structure, and the methodology to be described exploits that similarity.

ARMY TRAINING ADAPTATION

In the context of military training, we set up our model as follows. An individual or unit (squad, platoon, company, battalion, etc.) has a number of missions for which it is responsible. There are a number of different types of training activities in which the unit can engage, and each type of training activity makes some contribution to the ability of the unit to carry out each mission. To be sure, certain types of training may enhance ability in one mission area more than in another. The amount of each training activity undertaken by the military unit is measurable in appropriate units such as hours or trials. The overall ability and proficiency with which the unit carries out its assigned missions is referred to as the unit's effectiveness, and we assume a valid measure of group effectiveness exists or can be constructed. The costs of carrying out each type of training are also assumed to be known, and the unit's training budget is assumed known and fixed (for the current training period).

Suppose a new training concept is developed and is considered for introduction into this milieu. A procedure is needed to determine whether, and to what extent, the new training concept is economically viable. The basic approach is to determine whether the present value of the sum of the net values of the new training to each military unit utilizing that training over the "lifetime" of the training program exceeds the development cost of the training program. The key to implementing the approach is the determination of the net value of the new training to the unit using it. This can be accomplished using either one of two concepts from welfare economics.

The first is the compensating budget variation. Here one attempts to determine the maximum training budget reduction a unit can suffer in the presence of the new training program which still permits the previous level of effectiveness - the level reached with the initial budget and no new training - to be achieved. The second concept is the equivalent budget variation. Here one attempts to determine the minimum training budget increase which a unit must receive to achieve the same increase in effectiveness without the new training program as can be achieved with the initial budget and with the new training program. Under certain conditions, the compensating budget variation and the equivalent budget variation are numerically equivalent. More generally, however, they have different values.[11] Which of the two concepts provides the more appropriate measure of the value of the new training program depends on the objective of the organization. If the objective is to minimize the cost of achieving the current level of effectiveness, the compensating budget variation is more appropriate. If the objective is to increase effectiveness while maintaining the initial budget level, the equivalent budget variation is more appropriate. To the extent that the organization's objective is uncertain, or to the extent it combines both mentioned objectives, a weighted average of the two variations can be used.

The numerical values of both the compensating and equivalent budget variations can be derived from the effectiveness production function and the unit's training budget constraint. The effectiveness production function is the relationship between the inputs and output of the training process. The inputs are the various types and amounts of training the unit receives, along with the relevant attributes of the unit itself (such as intelligence and prior training) and the output is the assumed objective and measurable characteristic effectiveness. The training budget constraint is the relationship among the dollar value of the training budget, the unit costs of the various types of available training, and the quantities of each type of training which can be afforded.

The training budget constraint is a linear function and is conceptually straightforward. The effectiveness production function, on the other hand, is (in general) non-linear and is rich in possible specifications. In considering the impact on the production function of the introduction of a new training program, there appear to be four distinctly different ways in which a new program can affect effectiveness. First, the new program can influence effectiveness in the same

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[11]The reason for this asymmetry, which was first pointed out by A. Henderson ("Consumers Surplus and the Compensating Variation," Review of Economic Studies, 1941, is somewhat technical and unimportant for present purposes.

way that every other program does, i.e., it is simply another among many training programs. Second, the new program can enhance or augment the effect of one or several of other training programs, i.e., it can make it seem like more of some other training is being received than is actually the case. Third, the new program can uniformly augment all the other training, i.e., it can raise the entire effectiveness production function. Finally, the new training program can increase the substitutability of one type of training for another, permitting some of a less costly type of training to be substituted for some of a more costly type of training while maintaining the same level of effectiveness.

The effectiveness production function must be empirically determined. Multiple regression analysis is the logical starting point for this estimation process. The observations (data points) may be cross-sectional or longitudinal, or perhaps a pooled sample. The regressand is the effectiveness measure achieved by the unit. The regressors would be the amounts of each type of training, as well as such standardizing variables as intelligence and prior training, relevant to each effectiveness observation.

The training budget constraint, unlike the effectiveness production function, need not be empirically estimated, but can be constructed using available data.

DEVELOPMENT OF THE VALUATION METHODOLOGY

Assumptions. At this point we begin a somewhat rigorous development of the Valuation Methodology, which is the third of the four steps comprising this CTEA Methodology. We start with the following assumptions.

- Military training is carried out as a rational resource allocation process. The trainer behaves as if he knows the effectiveness production function[12] (the relation between inputs and outputs of the training process), he knows the costs[13] of the various types of training, he knows his training budget, and he attempts to maximize the effectiveness he can achieve in his charges subject to his cost and budget constraints.

- There exists a measure of unit effectiveness.

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[12] The trainer may have an implicit knowledge of the effectiveness function. That is, while he may not be able to state the mathematical form of the function, he behaves - in his resource allocation choices - as though he knows it. This is similar to the pocket billiards expert who may have no explicit knowledge of the principles of mechanics, but surely behaves as though he does. Step 1 of the CTEA Methodology involves the explicit estimation of the effectiveness production function.

[13] As in the previous footnote, it is sufficient to assume the trainer has an implicit, or behavioral, knowledge of these costs. Step 2 of the CTEA Methodology involves the explicit determination of the unit costs of each type of training.

- The effectiveness production function is a known, continuous, differentiable, strictly quasi-concave function with domain and range the nonnegative real numbers.

- The unit costs of each type of training are known, as is the total amount of the training budget.

- There are I (greater than one) different types of training available, not including the new training which is the subject of the evaluation.

Of these five assumptions, only the third demands elucidation at this point, the others being sufficiently self-explanatory.

We begin with a definition. The <u>effectiveness production function</u> (EPF) is the relation between any given amounts of any types of available training and the maximum level of effectiveness which that training can achieve, given the levels of experience, intelligence, etc. of the units being trained. An example of an EPF might be $E = T_1^{\alpha} \; T_2^{\beta} \; A$ where E = effectiveness, T_1 and T_2 are numerical measures of the amounts of two types of training received, A is a combined measure of experience and intelligence, and a, α, and β, are positive parameters.

Assumption 3 states the EPF is <u>known</u>. In order to carry out the Valuation Methodology, this must be the case. Determining the EPF is Step 1 in the CTEA Methodology.

The EPF is assumed to be continuous. This simply means there is an effectiveness level associated with all values of the training variables within the relevant range. Differentiable means the function has derivatives everywhere, there are no kinks or corners in the function. That the EPF is strictly quasi-concave means its contours (iso-effectiveness surfaces) are strictly convex to the origin. A nonnegative range and domain of the EPF simply means the values taken by inputs and the output of the function cannot be negative.

The following figures give three different perspectives on the EPF. In general, one can expect an EPF to have a form like that suggested by the figures, although deviations cannot be ruled out _a priori_. The reader might bear in mind that there are an infinite number of mathematical specifications of the EPF consistent with the displayed form, so these figures do not obviate the need for Step 1 of the CTEA Methodology. Figure 1 displays a cross-sectional view of the EPF. Holding all other variables constant, it shows the relation between one type of training and unit effectiveness. Three points are noteworthy. First, zero amount of training does not imply zero effectiveness. This is because the other factors affecting effectiveness, held constant for the purpose of this Figure, contribute to the unit's effectiveness. Even if none of this particular type of training is received, the unit can exhibit a positive level of effectiveness, such as A. Second, the curve in the figure approaches the effectiveness value B asymptotically. This means there is a maximum level of effec-

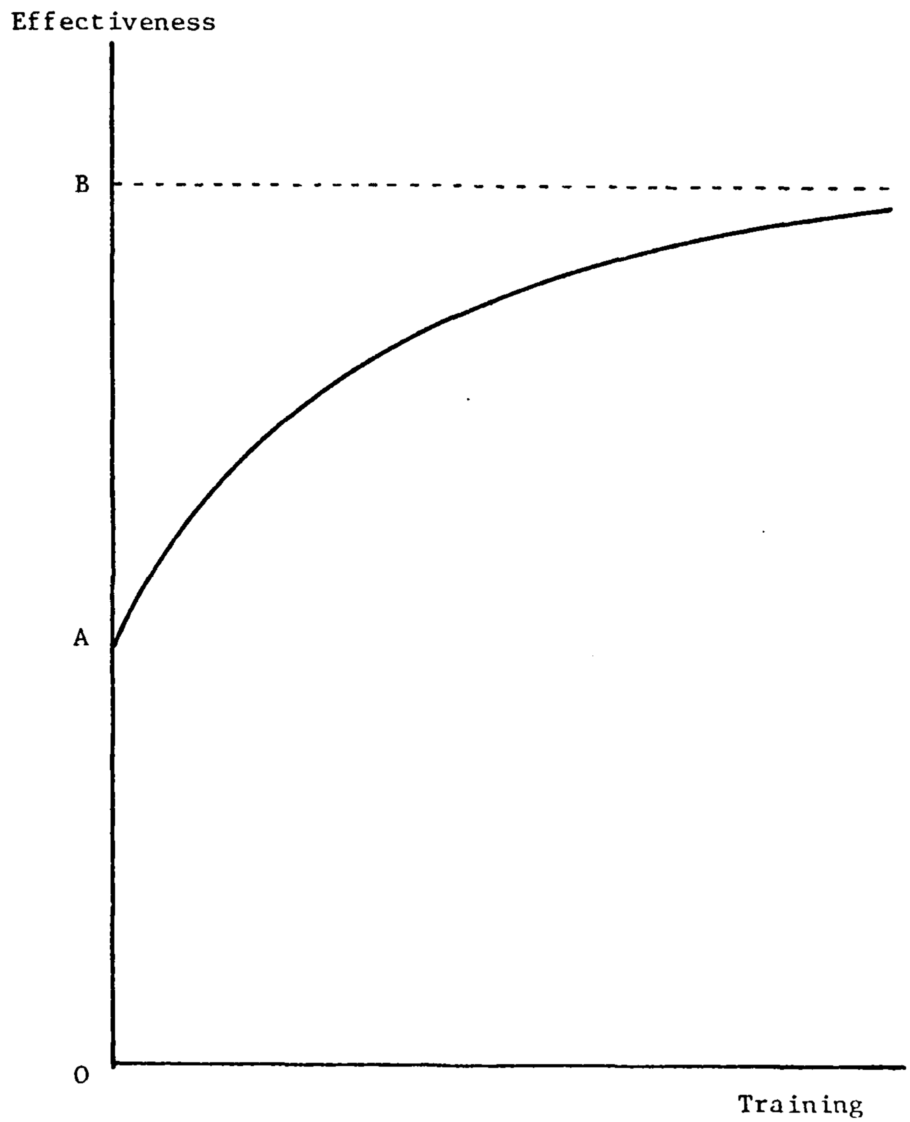

Figure 1. Cross-sectional View of the Effectiveness Production Function: Effectiveness Versus Training.

tiveness which can be produced from any amount of this type of training, given the fixed levels of the other factors. This assumption is in good accord with both the economic theory of production functions and psychological theories of training. Third, the curve in Figure 1 is non-decreasing as the level of training increases. In other words, more training never causes a decrease in effectiveness.

Figure 2 shows an alternate cross-sectional view of the EPF. Holding all factors constant except for two types of training, the Figure shows all combinations of the two types of training, other factors constant, which can lead to a given level of effectiveness. The two curves shown in the figure correspond to two different levels of effectiveness, the greater effectiveness being associated with the more north-easterly curve. These curves can be referred to as iso-effectiveness contours, and there are four noteworthy points about these contours. First, they slope downward from left to right. This indicates that one type of training can be substituted for another to maintain a given level of effectiveness. Second, the contours are non-intersecting. If intersections occurred, this would imply that both contours were associated with the same effectiveness level, which would be a contradiction. Third, the contours are convex to the origin, i.e., their slopes increase to the right. This means that as one type of training is substituted for another, it takes more and more of the increasing type of training to compensate for unit decreases in the

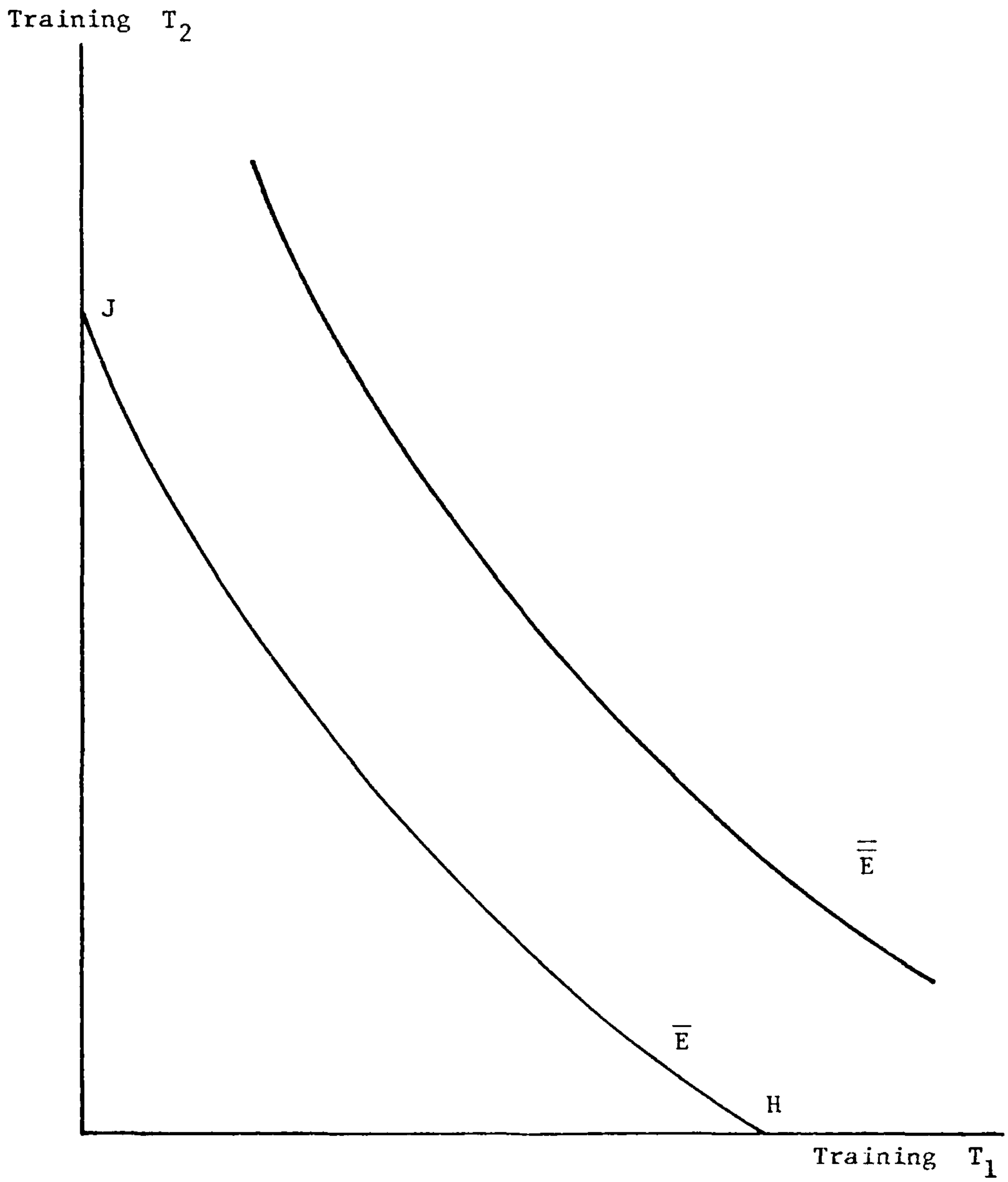

Figure 2. Cross-sectional View of the Effectiveness Production Function: Training Versus Training.

other type training if the initial level of effectiveness is to be maintained. The fourth point is that the iso-effectiveness contours may or may not intersect the axes. Typically one might expect the contours associated with the lower effectiveness levels to intersect the axes while the higher contours may not. This means that for lower effectiveness levels (say $\overline{E}$) some types of training may be dispensed with entirely (other types substituting) and that level of effectiveness maintained. For high levels of effectiveness (say $\overline{\overline{E}}$), at least some amount of certain types of training may be indispensable if that effectiveness level is to be maintained.

Figure 3 is a three dimensional view of the EPF. It combines the views of the previous two figures. Holding all variables constant except two types of training and effectiveness, the EPF can be represented as surface ADE. A is greater than 0 here as in Figure 1. As T_1 increases with $T_2 = 0$, the value of effectiveness asymptotically approaches B. Likewise, as T_2 increases with $T_1 = 0$, the value of effectiveness asymptotically approaches C. If effectiveness is fixed at level $\overline{E}$, locus GF is the iso-effectiveness contour representing all combinations of T_1 and T_2 yielding $\overline{E}$. JH is the projection of GF onto the plane of T_1 and T_2, represented in Figure 2.

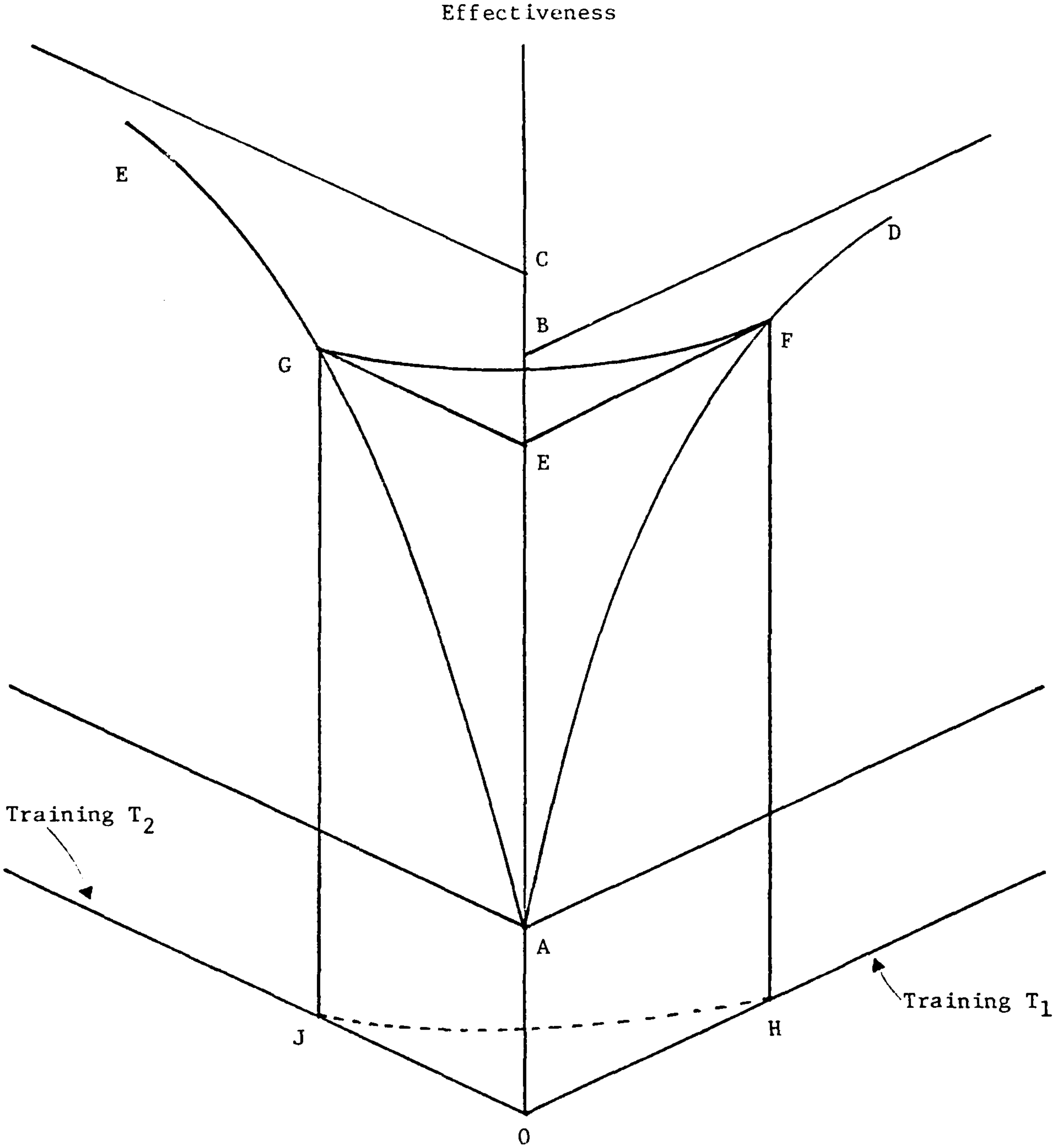

Figure 3. Three Dimensional View of the Effectiveness Production Function.

The Model. We are now prepared to construct the economic model of training resource allocation, which is the basis for the CTEA Methodology. We employ the following notation.

E	a unit's level of overall effectiveness
T_i	the quantity of training of type i received by the unit, $i = 1 \ldots I$
T_*	the quantity of the new training program received by the unit
c_i	the per unit cost of T_i
c_*	the per unit cost of T_*
B	the dollar amount of the unit's training budget
A	all other factors affecting the unit's mission proficiency
$C(T_*)$	the compensating budget variation associated with T_*
$E(T_*)$	the equivalent budget variation associated with T_*
$V(T_*)$	the net value of T_* to the unit.

In what follows we employ an implicit form of the EPF, in order to make our development of the CTEA methodology as general as possible. Of course, in an actual application, a specific EPF would be employed.

Denote the EPF as

$$E = F\ (\ T_1,\ T_2,\ \ldots\ T_1,\ A\ ). \qquad (1)$$

Remember that $E{=}F(\cdot)$ incorporates all the assumptions about the EPF mentioned previously. The trainer's objective is to maximize E, but he is constrained by limited resources. Specifically, his choices over the T_1, T_2, ..., T_I (his control variables) must obey (assuming he spends his entire training budget, $\overline{B}$)

$$\overline{B} = c_1 T_1 + c_2 T_2 + \ldots + c_I T_I \qquad (2)$$

and

$$T_i \geq 0, \quad \forall i \qquad (3)$$

Equation (2) states the trainer can spend only as much budget as he has, and (3) is merely a technical statement that the amount of training of any type cannot be a negative number. Equations (1), (2), and (3) constitute a nonlinear programming problem. Since this is the resource allocation problem providing the foundation for our CTEA Methodology, some investigation into its characteristics is useful. Specifically, let us characterize the solution to the problem and then investigate the effects of changes in parameter values (B, C_1, ...) on the solution.

The method of Lagrange Multipliers[14] is a useful solution technique for maximizing (1) subject to (2) and (3). Form the function

$$L = F\,(T_1, T_2, \ldots, T\ ) + \lambda\,(B - c_1 T_1 - c_2 T_2 - \ldots - c_I T_I).$$

First order conditions for a maximum are

[14] See almost any text on advanced calculus.

$$\partial L/\partial T_1 = \partial F/\partial T_1 - \lambda c_1 = 0$$

$$\partial L/\partial T_2 = \partial F/\partial T_2 - \lambda c_2 = 0$$

$$\cdots\cdots\cdots\cdots\cdots\cdots\cdots \qquad (4)$$

$$\partial L/\partial T_I = \partial F/\partial T_I - \lambda c_I = 0$$

$$\partial L/\partial \lambda = B - c_1\, T_1 - c_2\, T_2 - \ldots - c_I\, T_I = 0$$

The first I conditions in (4) can be reduced to the I-1 conditions

$$\frac{\dfrac{\partial F}{\partial T_i}}{\dfrac{\partial F}{\partial T_I}} = \frac{c_i}{c_I}, \text{ for } i = 1 \text{ to } I\text{-}1 \qquad (5)$$

For the two variable case, the right side of (5), c_1/c_2, is simply the negative of the slope of (2) in T_1T_2 space. The meaning of the left side of (5) can be seen as follows. For the two variable case the total differential of (1) is

$$dE = \frac{\partial F}{\partial T_1}\, dT_1 + \frac{\partial F}{\partial T_2}\, dT_2.$$

Along an iso-effectiveness contour dE = 0, so that

$$\frac{dT_2}{dT_1} = - \frac{\partial F/\partial T_1.}{\partial F/\partial T_2}$$

Therefore, the left side of (5) is the negative of the slope of the optimal iso-effectiveness contour. It follows that (5) implies that the optimal values of T_1 and T_2 are such that at that point the slope of the iso-effectiveness contour equals the slope of the budget constraint. Moreover, according to the I+1st condition in (4), the optimal T_1 and T_2 must be on the budget constraint. Figure 4 summarizes these conclusions by graphically illustrating the solution to the two variable problems. The solution occurs where the highest iso-effectiveness contour has a point in common with the budget line. Tangency of the two lines occurs at that point.

Note that the rationale for the assumption of strict quasi-concavity of the EPF is now evident. Strictness insures that the iso-effectiveness contour has no linear segments. If it exhibited linearity, the optimum solution either could be indeterminate (if the iso-effectiveness line and the budget line happened to have the same slope) or could occur at a corner, such as at $(T_1, T_2) = (B/c_1, 0)$ or $(0, B/c_2)$. The corner solution is the most likely event, yet is not plausible in most cases. Thus, the assumption of strict quasi-concavity of the EPF helps rule out the implausible event, and helps the model conform (presumably) more closely to reality.

As a check on the reasonableness of the model, and as a way of investigating its characteristics, we can determine the model's implications for training resource allocation when (a) the per unit cost of one type of training changes; or (b) the training budget changes. Both these situations can be investigated with the aid of diagrams akin to Figure 4. Suppose we begin with the solution es-

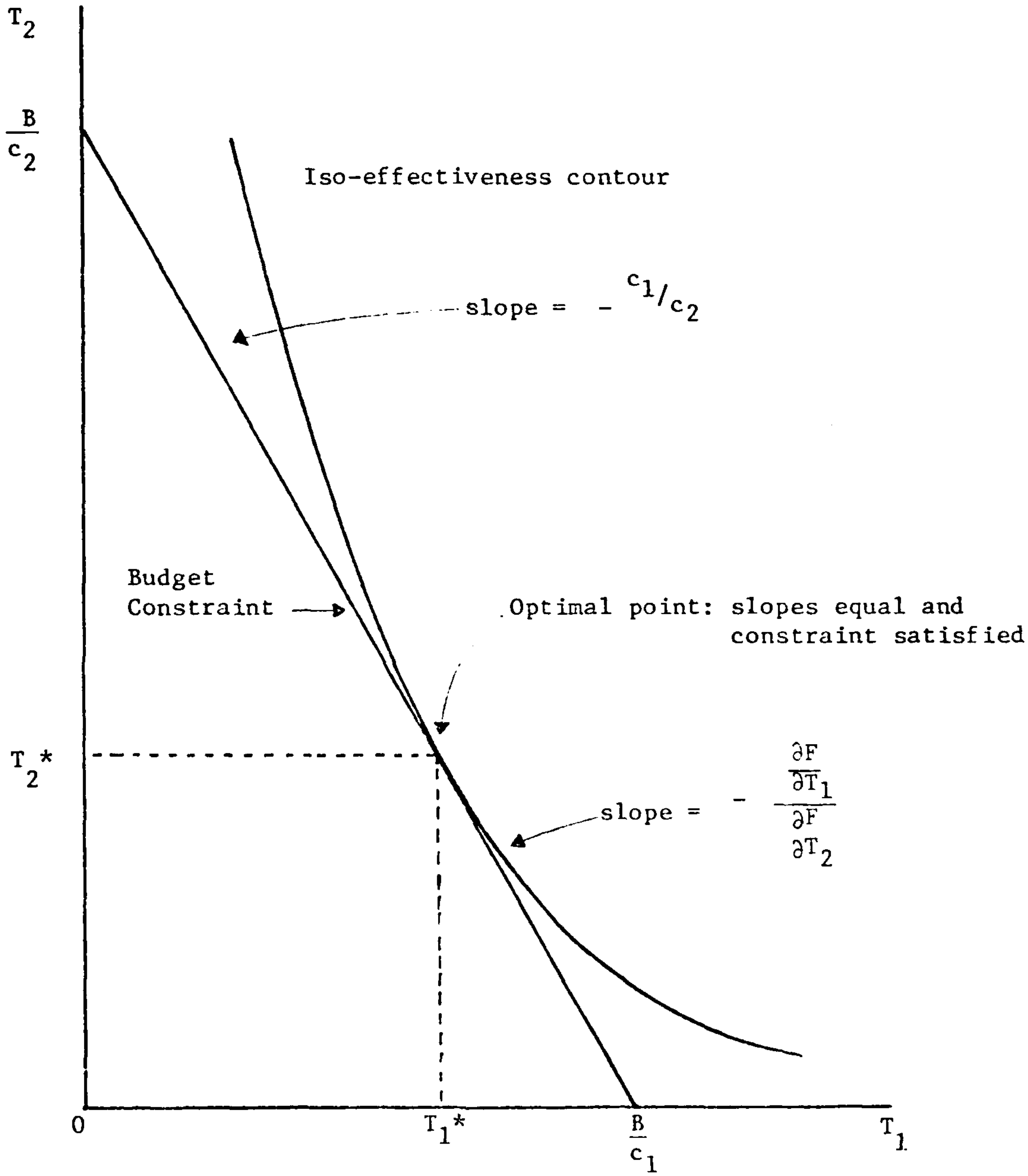

Figure 4. Illustration of Solution to the Training Resource Allocation Problem $(T_1{}^*{}_1T_2{}^*)$ is the optimal solution.

tablished in Figure 4 and then assume an increase to c_1(the per unit cost of T_1) occurs, but B and c_2 remain constant. An increase in c_1 means that B/c_1 decreases, which means that the budget constraint rotates (about B/c_2) inward. Figure 5 illustrates this change in the budget constraint, and the tangency of a lower iso-effectiveness contour to the new constraint line. Figure 6 isolates the effect of the change in the per unit cost of T_1 on the amount of T_1 which is optimally employed. In almost all cases[15], the optimal level of T_1 declines with increase in c_1. In this case, the optimal level of T_1 goes from T_1 to $\overline{T}_1$. Many points like (T_1, c_1) can be generated by arbitrarily changing c_1 in Figure 5, and tracing the effect in Figure 6. The locus formed by all such points (in Figure 6) would be known as the training demand curve for T_1. D in Figure 6 is such a curve, here drawn from only two points. The downward slope at D reflects the law of demand, which states that there is an inverse relation between the unit price of a good and the quantity which will be demanded. The law of demand is a fundamental concept in microeconomic theory.

Now, beginning again from Figure 4, consider the effect of an increase in the training budget on T_1 (the effect on T_2 could just as easily be considered). An increase in B shifts the budget constraint outward, but parallel to the initial constraint. The effect of the shift on the optimal level of T_1 cannot be predicted without detailed information on the shape of the iso-effectiveness contours. The optimal

[15] That is for almost all sets of convex iso-effectiveness contours.

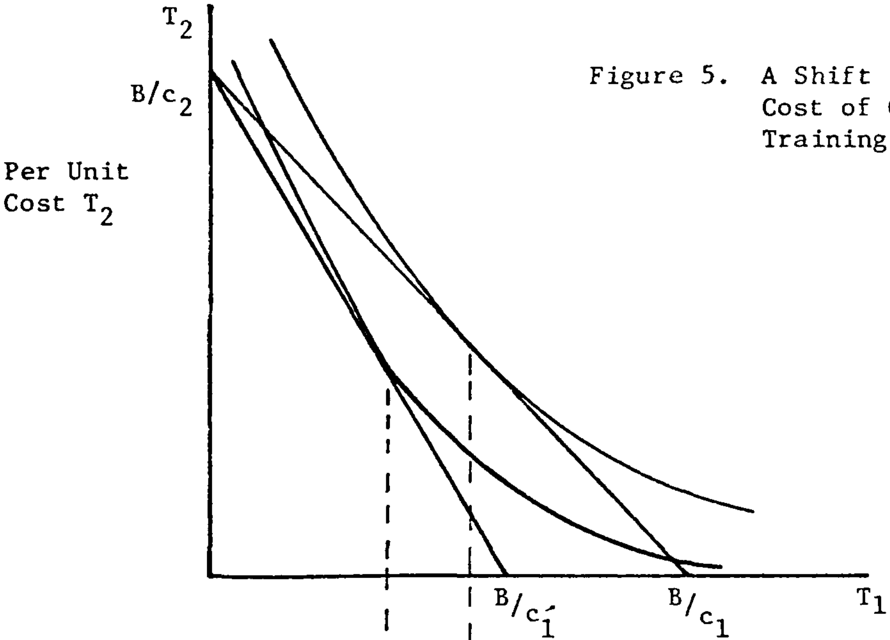

Figure 5. A Shift in the Per Unit Cost of One Type of Training.

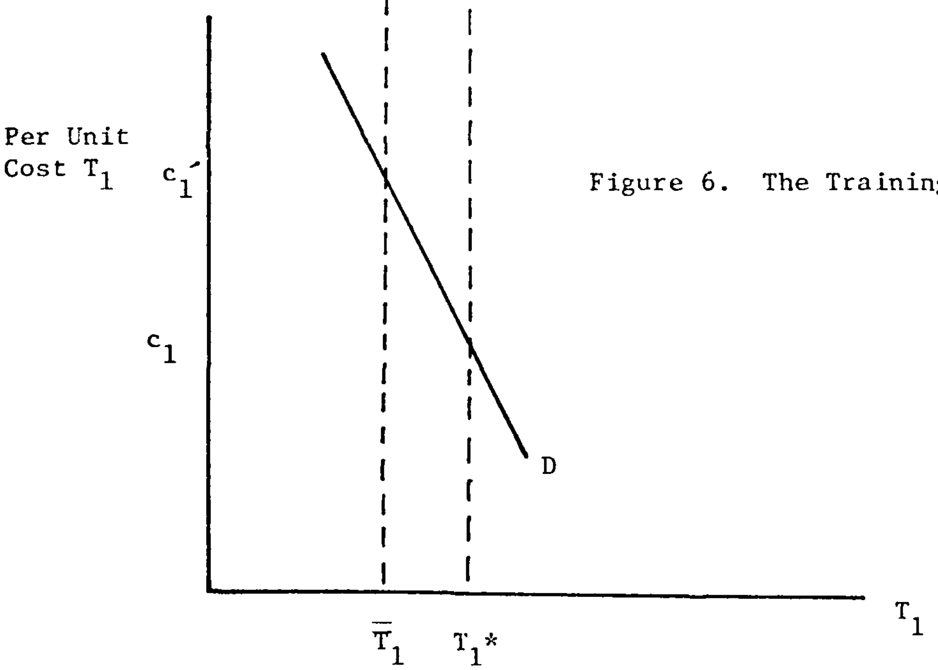

Figure 6. The Training Demand Curve.

level of T_1 could increase, decrease[16], or remain unchanged as B increases. Figures 7, 8, and 9 illustrate these possibilities. In each figure B represents the initial budget line, and B' the new budget line. T_1* represents the initial optimal value of T_1, and $\overline{T}_1$ the new optimal value; I* and $\overline{I}$ are the initial and final iso-effectiveness contours.

The characteristics of the model revealed in equations (4) and (5), and in Figures 4, 5, and 6 parallel the characteristics of the standard microeconomic theory of the consumer. The latter having withstood a good deal of initial investigation, it is not imprudent to accept the reasonableness of the former, and use it as the basis of the valuation methodology.

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[16] A decrease could occur in one type of training if that training were inexpensive but not very effective. An increase in the training budget could cause the trainer to substitute more costly, but more effective, training for that initial training. Thus, one might observe a decrease in a certain type of training associated with an increase in another type of training.

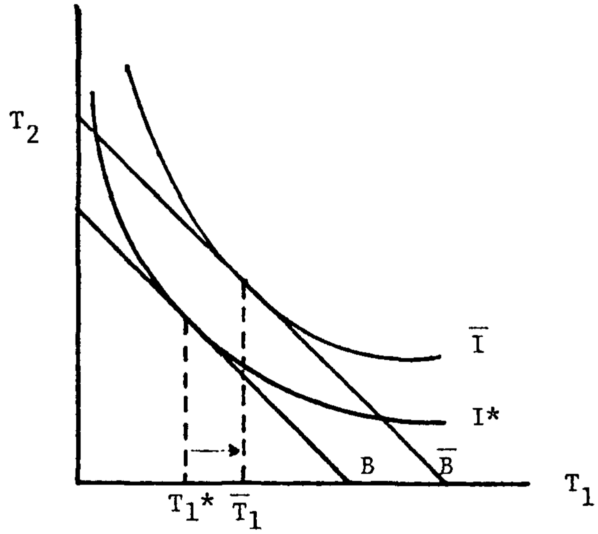

Figure 7. An increase in Budget causes an Increase in T_1.

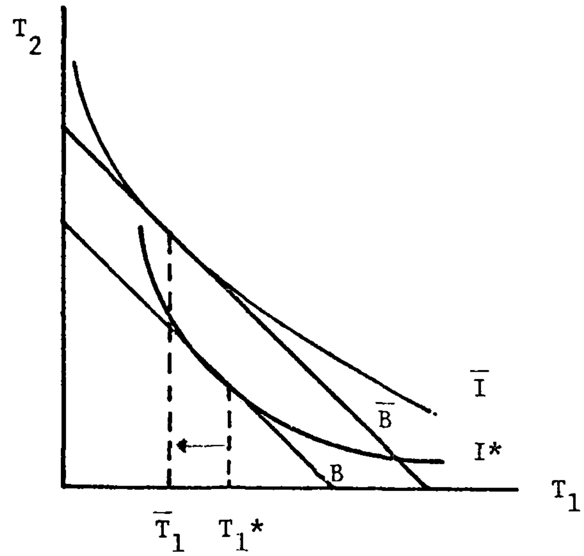

Figure 8. An Increase in Budget causes a Decrease in T_1.

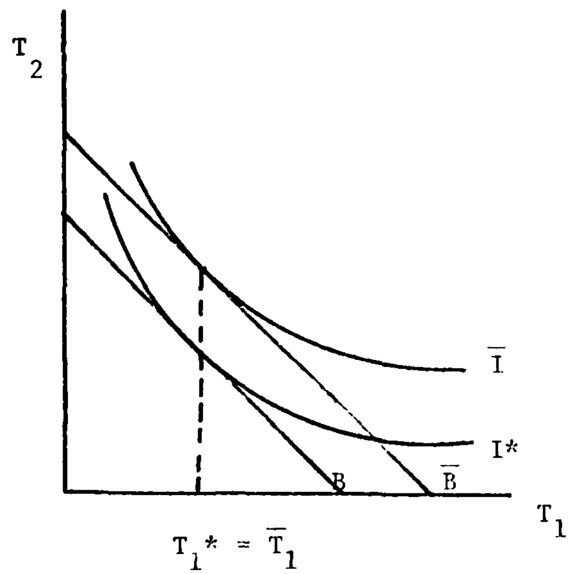

Figure 9. An Increase in Budget causes no change in T_1.

The Valuation Methodology. Having presented our model of training resource allocation, we are now prepared to develop the training valuation methodology. The methodology exploits the economic aspects of the resource allocation model to infer the economic value of a specific type of training.

Suppose our interest in a new type of training program T_*, whose per unit cost is c_*. At issue is whether, and to what extent, the benefits derived from T_* exceed the costs. Or in other words, is the net value of the T_* training program positive, negative, or zero? In yet other words, are we economically better or worse off by having the T_* training program?

These questions can be answered by calculating the compensating budget variation and/or the equivalent budget variation associated with T_*. These concepts were developed in the field of welfare economics to measure the impact on consumers of price changes. Our use of the concepts here extends their applicability beyond the measurement of price effects to the measurement of the value of training programs.

The compensating budget variation may be defined as the reduction in the initial training budget which will maintain the initial level of effectiveness when the new type of training is introduced where the initial effectiveness level was achieved with the initial budget level but without the new training program.

This concept of compensating budget variation can be clarified by resorting to the symbolic notation introduced above. Let $\overline{B}$ denote the initial training budget level, and I the initial number of training programs. The trainer's resource allocation problem is, using (1), (2), and (3) introduced above.

$$\text{MAXIMIZE} \quad E = F\,(T_1, T_2, \ldots, T_I, A) \tag{1}$$

$$\text{given that } \overline{B} = c_1\,T_1 + c_2\,T_2 + \ldots + c_I\,T_I \tag{2}$$

$$T \geq 0\ ,\ \forall i \tag{3}$$

Let us denote the solution to this problem as $(\overline{T}_1, \overline{T}_2, \ldots, \overline{T}_I)$, which results in an effectiveness level $\overline{E}$.

Now suppose a new type of training, T_*, is introduced, with unit cost c_*. The trainer is free to use as much or as little of T_* as he chooses (subject to c_* and $\overline{B}$). How much of the budget can now be saved by incorporating T_* into the training schedule? We answer this by finding the minimum budget which will permit $\overline{E}$ to be achieved. Anlytically, the problem is

$$\text{MINIMIZE} \quad B = c_1\,T_1 + c_2\,T_2 + \ldots + c_I\,T_I + c_*\,T_* \tag{4}$$

$$\text{given that} \quad \overline{E} = F\,(T_1, T_2, \ldots, T_I, T_*, A) \tag{5}$$

$$T_i,\ T_* \geq 0,\ \forall i \tag{6}$$

Denote the solution to this problem as $(\breve{T}_1, \breve{T}_2, \ldots, \breve{T}_I, \breve{T}_*)$, and the corresponding minimized budget value as $\breve{B}$. Then the savings achieved by the use of T_* in the achievement of $\overline{E}$ level of E are $\overline{B} - \breve{B}$. The quantity is known as the compensating budget variation associated with T_*, which we denote as $C(T_*)$. That is

$$C\,(T_*) = \overline{B} - \breve{B}. \tag{7}$$

We note that $C\ (T_*)$ is necessarily non-negative. For the maximum value of B in (4) is $\overline{B}$ achieved by setting $T_* = 0$. If T_* is brought into the solution at a positive level, it cannot be a detriment to the value of B, otherwise it simply would remain at 0. In other words, if T_* is not useful in cutting costs and maintaining effectiveness, it will not be used. It can help, but it can't do any harm.[17] Therefore, if the maximum value of B is $\overline{B}$, the minimum value of $C\ (T_*)$ is 0.

The compensating budget variation is an appropriate measure of the value of a training program when the goal of that new training is to save money, that is, when the new training is neither expected nor desired to result in an overall increase in effectiveness. When an implicit or explicit goal of the new training is to enhance effectiveness, not simply to cut costs, the compensating budget variation alone is not an appropriate measure of training value. The appropriate measure in this latter case must include the equivalent budget variation, which measures the value of the increased effectiveness attributable to the new training program as the minimum incremental cost of achieving the higher level of effectiveness <u>without</u> the new training program. Once again, resort to symbolic notation may clarify the issue. If T_* is introduced into the training milieu, and the initial budget

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[17] At this point the development cost of T_* has yet to be considered.

level $\overline{B}$ prevails, the resource allocation problem is

$$\text{MAXIMIZE} \quad E = F\,(T_1, T_2, \ldots, T_I, T_*, A) \tag{8}$$

$$\text{given that} \quad \overline{B} = c_1\, T_1 + c_2\, T_2 + \ldots + c_I\, T_I + c_*\, T_* \tag{9}$$

$$T_i,\ T_* \geq 0, \quad \forall\, i \tag{10}$$

The reader will note that problem (8), (9), (10) is different from problems (1), (2), (3) and (4), (5), (6). Denote the solution to (8), (9), (10) as $\hat{T}_1, \hat{T}_2, \ldots, \hat{T}_I, \hat{T}_*$, with resultant effectiveness E. Then solve

$$\text{MINIMIZE} \quad B = c_1\, T_1 + c_2\, T_2 + c_I\, T_I \tag{11}$$

$$\text{given that} \quad \hat{E} = F\,(T_1, T_2, \ldots, T_I, A) \tag{12}$$

$$T_i \geq 0 \quad \forall i \tag{13}$$

Denote the solution to this problem as $\tilde{T}_1, \tilde{T}_2, \ldots, \tilde{T}_I$, and the resulting minimized budget value as $\hat{B}$. Then, the equivalent budget variation is

$$E\,(T_*) = \hat{B} - \overline{B} \tag{14}$$

Note that $E\,(T_*)$ must be non-negative. A comparison of (1), (2), and (3) with (8), (9), and (10) reveals the only difference is that the latter problem allows the possibility of using T_*. The extreme worst case would be $T_* = 0$, which would mean that $\hat{E}$ would be equal to $\overline{E}$. In that case, the solution to (11), (12), (13) would be $\hat{B} = \overline{B}$, and $E\,(T_*)$ would be 0. If the extreme worst case does not prevail, i.e. $T_* > 0$, then $E\,(T_*) > 0$.

There is no necessary relation between the magnitudes $C(T_*)$ and $E\,(T_*)$, that is, $C\,(T_*) \lesseqqgtr E\,(T_*)$. However, if $V\,(T_*)$ is defined as the best estimate of the value of T_*, we should have

$$V\ (T_*) = \lambda \cdot C\ (T_*) + (1-\lambda) \cdot E\ (T_*) \tag{15}$$

for $0 \leq \lambda \leq 1$.

That is, $V\ (T_*)$ should be chosen so it falls between $C\ (T_*)$ and $E\ (T_*)$, inclusively. λ is a weight denoting the relative importance of the cost saving objective in the introduction of T_*. $(1 - \lambda)$ is the weight associated with the effectiveness enhancement objective of T_*. To allay the reader's concern that the introduction of λ necessarily causes $V\ (T_*)$ to span so broad a range as to mitigate its usefulness, we note here that for a broad and useful class of effectiveness production functions, $C\ (T_*) = E\ (T_*)$. Thus, $V\ (T_*)$ can be independent of λ. For other types of EPF's, $C\ (T_*)$ and $E\ (T_*)$ can be reasonably close.

Three Geometric Expositions of the Valuation Methodology. An appreciation of the methodology developed in the previous section can be gained by considering several geometric interpretations. Each geometric interpretation makes slightly different assumptions in abstracting the essence of the model to achieve a two dimensional interpretation. In the first interpretation we assume there are two types of training (T_1 and T_2) in addition to the new training T_*. We also assume that while T_1 and T_2 have positive unit costs, c_1 and c_2, the unit cost of T_*, c_*, is zero. In Figure 10, the line designated L_1 is the initial budget constraint. That is, L_1 is the line determined by the equation $\overline{B} = c_1 T_1 + c_2 T_2$. The curved lines are the iso-effectiveness contours of the production function. The initial optimal solution is $\overline{T}_1$, $\overline{T}_2$ yielding $E = \overline{E}$, when $T_* = 0$. When T_* becomes available a new optimization results in solution values $\hat{T}_1$, $\hat{T}_2$, yielding $\hat{E}$ at point D. $\overline{E}$ can be achieved with $T_* > 0$ at point K with a budget of $\breve{B}$. $\hat{E}$ can be achieved without T_* ($T_* = 0$) only by expanding the budget to $\hat{B}$, causing a solution at M. Then we can determine $C(T_*) = \overline{B} - \breve{B}$ and $E(T_*) = \hat{B} - \overline{B}$.

Alternatively, we can assume there is only one other type of training beside T_*, and that T_* has unit cost to the group of c_*. Figure 11 represents this abstraction. Initially, with budget $\overline{B}$ and only training type T_1 available, the group receives $\overline{T}_1 = \overline{B}/c_1$ units of T_1, resulting in an effectiveness level of $\overline{E}$. When T_* becomes available, the new

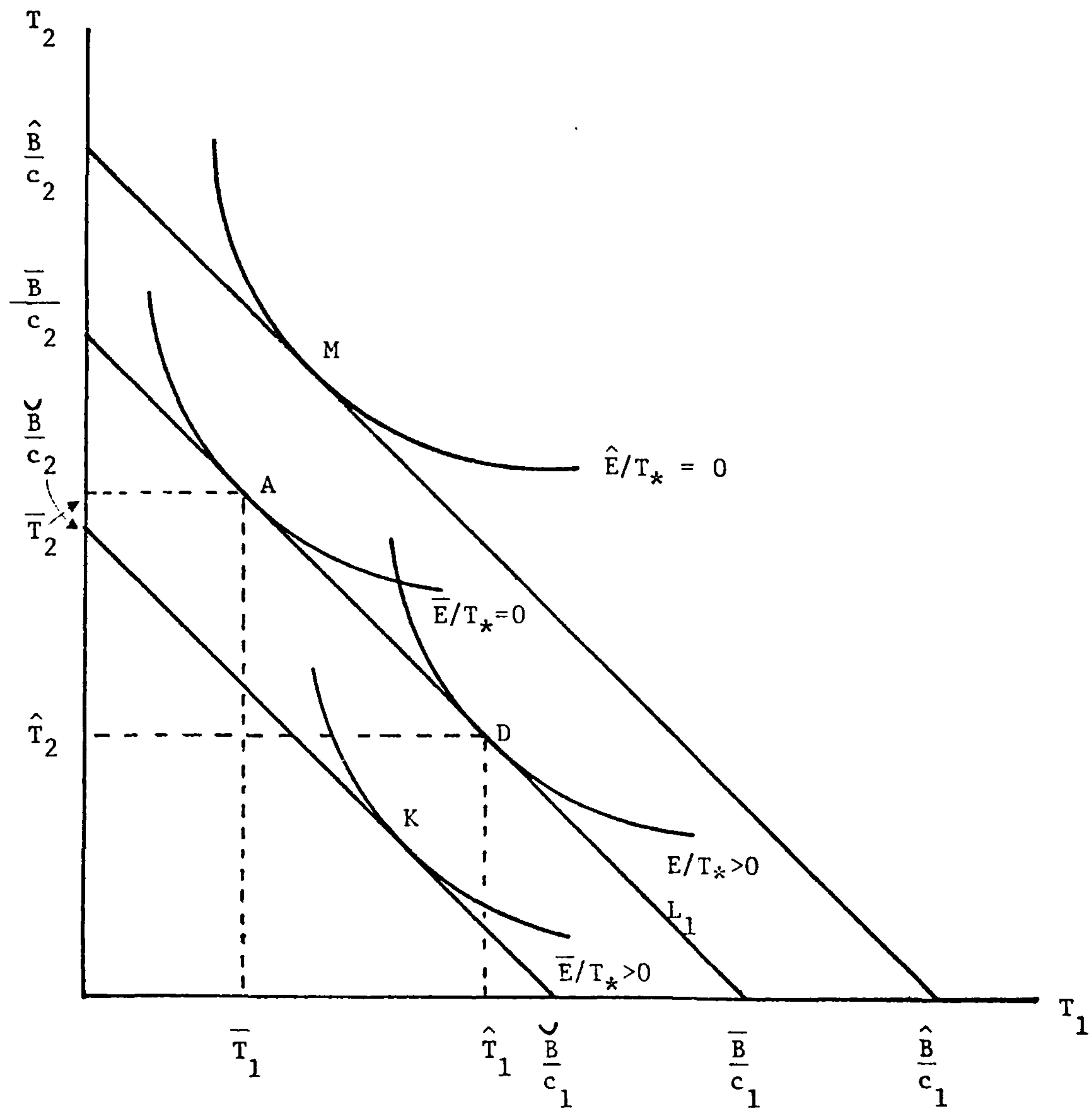

Figure 10. First Geometric Interpretation of Methodology.

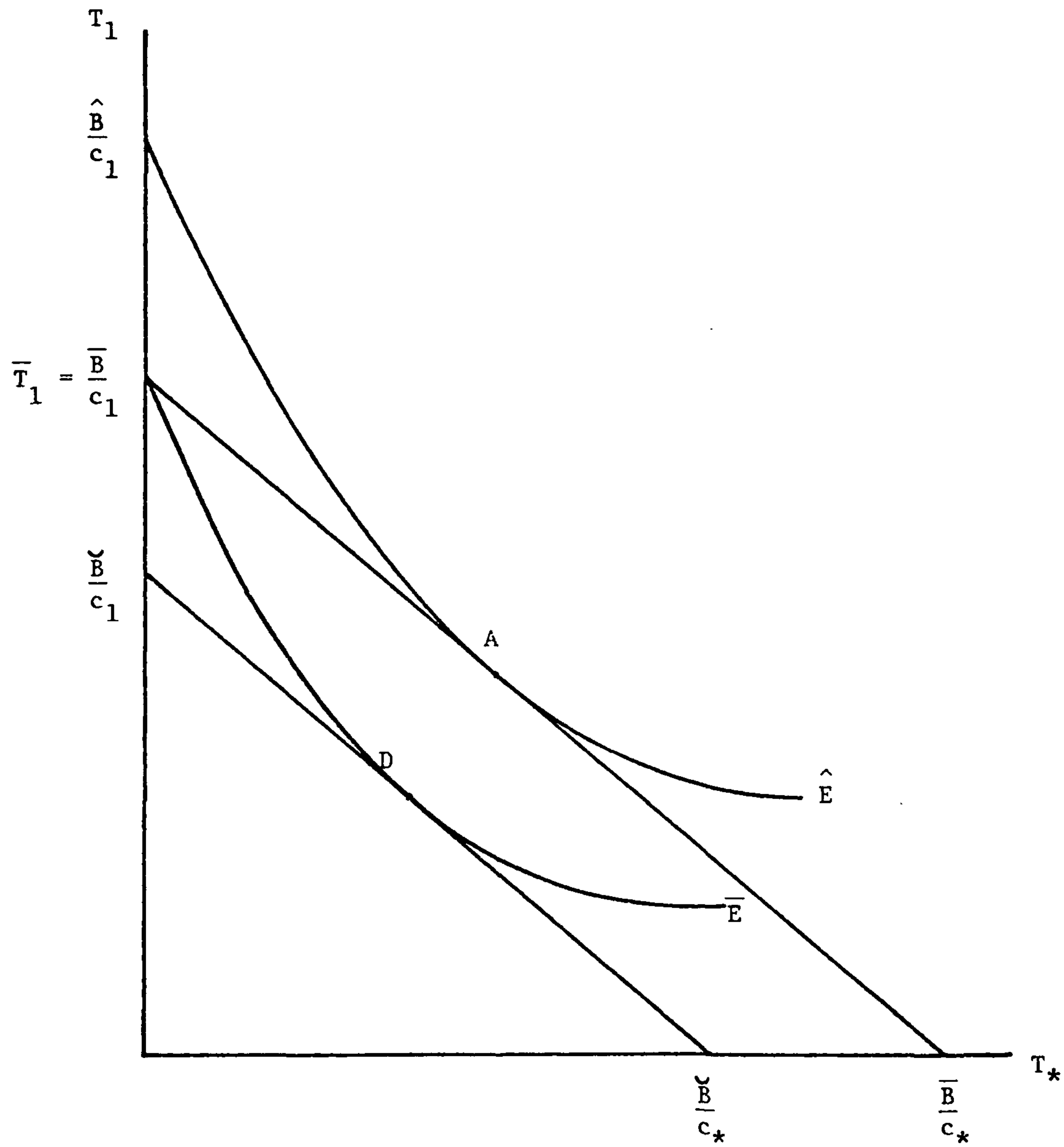

Figure 11. Second Geometric Interpretation of Methodology.

optimum training package is denoted by A, resulting in a higher effectiveness level of $\hat{E}$. $\bar{E}$ can be achieved with T_* with a budget of only $\breve{B}$, as indicated by point D. And $\hat{E}$ can be achieved without T_* only with the greater budget of $\hat{B}$, as indicated along the vertical axis. Once again, $C(T\ ) = \bar{B} - \breve{B}$, and $E(T_*) = \hat{B} - \bar{B}$.

Finally, we can avail ourselves of what might be referred to as the Effectiveness Cost Function (ECF), a relationship between the budget expenditure and the level of effectiveness, showing the greatest level of effectiveness which can be achieved with any given budget level. In Figure 12, the lower curve is the ECF when T_* is unavailable, and the upper curve is the ECF with T_*. In this representation, we can assume an arbitrary number of training types besides T_*, as well as an arbitrary unit cost of T_*. Initially the budget level is $\bar{B}$, T_* is unavailable, and the resulting effectiveness level is $\bar{E}$. When T_* is introduced, the same budget, $\bar{B}$, can now achieve $\hat{E}$. The initial effectiveness level, $\bar{E}$, can now be achieved with the lower budget, $\breve{B}$. And, in the absence of T_*, $\hat{E}$ could be achieved only by expanding the budget to $\hat{B}$. Again, $C(T_*) = \bar{B} - \breve{B}$, and $E(T_*) = \hat{B} - \bar{B}$.

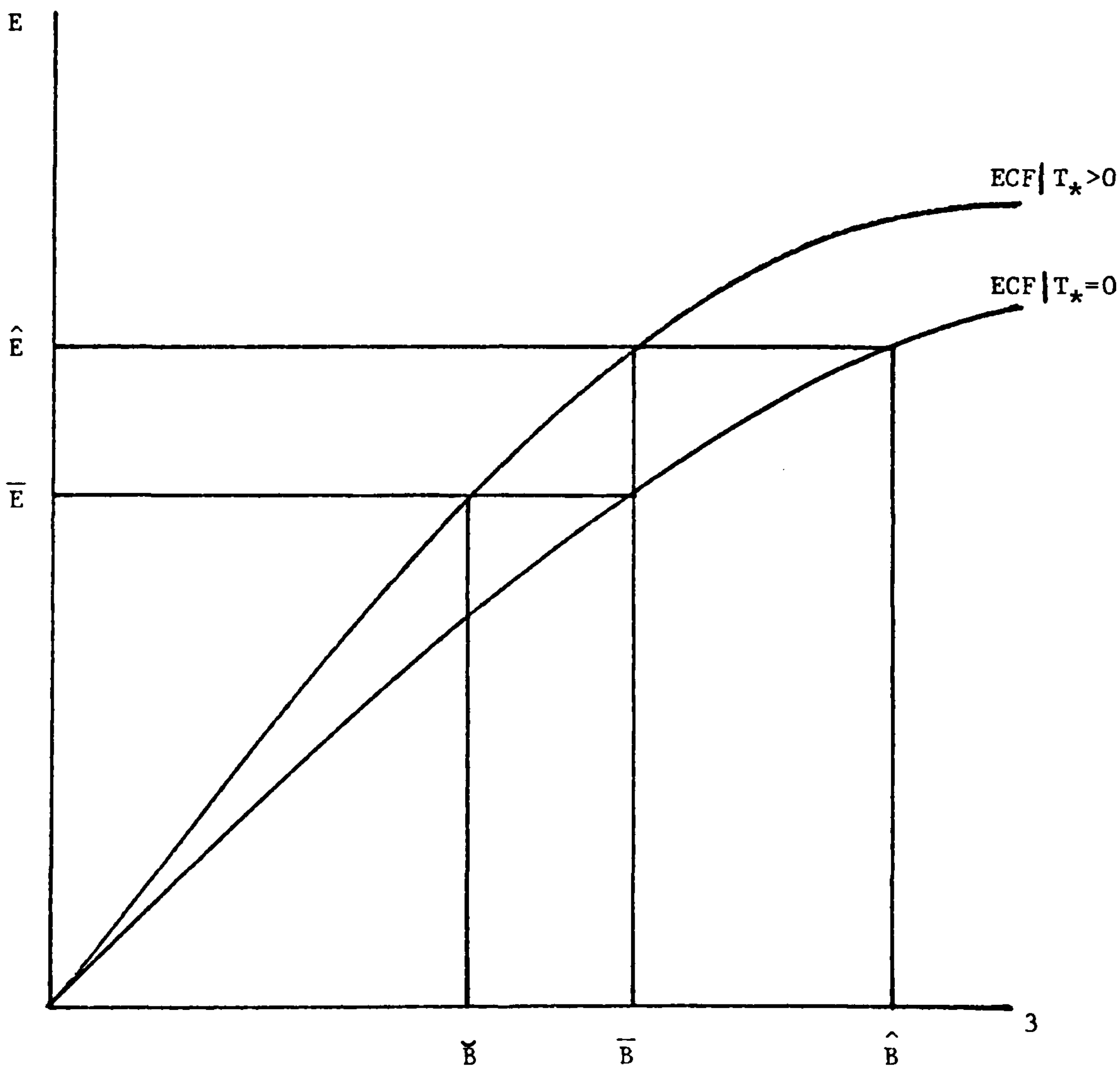

Figure 12: Third Geometric Interpretation of Methodology.

ALGEBRAIC EXAMPLE OF THE VALUATION METHODOLOGY

The purpose here is to illustrate the calculation of the compensating budget variation and the equivalent budget variation for a given effectiveness production function and a given budget constraint.

For the given effectiveness production function consider there are two types of conventional training - garrison training and field training - and TEC training, the new training, the value of which is to be determined. Consider, also, a single variable A represents the effectiveness of a unit based on "all other factors" before the unit commences conventional training and TEC training, and another variable E represents the effectiveness of a unit based on its ARTEP or other evaluation after the unit personnel have received conventional and TEC training. Consider, further, that for a number of like units, say k, over the course of their training periods, data are collected from which to determine for each unit

- the number of hours expended on each of the three types of training
- a numerical value (range 0 - 1) for A, and a numerical value (range 0 - 1) for E.

Finally, consider that several candidate effectiveness production functions are used in regression or other analyses of the k data points, and that the best "fit" EPF is

$$E = 1 + \left[A - 1\right] \left[1 - m\,(1 - e^{-gG})\right] \left[1 - m\,(1 - e^{-tT})\right] \left[e^{-fF}\right] \tag{16}$$

where G, T, and F are variables representing hours of garrison, TEC, and field training; g, t, and f are parameters representing learning rates associated with the respective types of training; m is the maximum level of effectiveness a unit might attain from either all garrison or all TEC training; and A and E are as explained above.

For the given budget constraint consider first that the hourly cost for each type of training exists so that the expression

$$B = \gamma G + \tau T + K + \phi F \tag{17}$$

represents the cost of various mixes of the three types of training where γ, τ, and ϕ are the hourly costs of garrison, TEC, and field training, and K is a fixed cost associated with any amount of TEC training (provided that TEC is used). Consider second that B denotes a fixed budget available for training so that

$$\overline{B} = \gamma G + \tau T + K + \phi F \tag{18}$$

is the budget constraint - i.e., only those mixes of G, T, and F whose total cost does not exceed $\overline{B}$ are permissible.

Now, there are four steps to carry out. In turn they determine

- the maximum value of E attainable with $\overline{B}$ and with no T. This value is denoted $\overline{E}$.

- the maximum value of E attainable with $\overline{B}$ and with T. This value is denoted $\hat{E}$.

- the minimum budget with which $\overline{E}$ can be achieved with T. This budget amount is denoted $\breve{B}$.

- the minimum budget with which E can be achieved with no T. This budget amount is denoted $\hat{B}$.

Note that this first is necessary to perform the third, and the second is necessary to perform the fourth. When $\breve{B}$ and $\hat{B}$ are determined, C(T) and E(T), the compensating budget variation and the equivalent budget variation, can be calculated, since B is known <u>a priori</u>. Specifically, $C(T) = \overline{B} - \breve{B}$ and $E(T) = \hat{B} - \overline{B}$.

The first step is accomplished by solving the problem

$$
\begin{aligned}
\text{MAX} \quad & E = 1 + \left[A - 1\right]\left[1 - m \ (1 - e^{-eG})\right]\left[1 - m \ (1 - e^{-tT})\right]\left[e^{-fF}\right] \\
\text{given} \quad & \overline{B} = \gamma G + \tau T + K + \phi F \\
& T = 0 \qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad (19) \\
& G,\ F \geq 0.
\end{aligned}
$$

The relevant Langrangian expression is

$$L = 1 + \left[A - 1\right] \left[1 - m\,(1 - e^{-gG})\right] \left[e^{-fF}\right] + \lambda \left[\overline{B} - \gamma G - \phi F\right]. \quad (20)$$

First order conditions are

$$\frac{\partial L}{\partial G} = \left[A - 1\right] \left[e^{-fF}\right] \left[e^{-gG}\right] \left[-mg\right] - \lambda\gamma = 0 \quad (21)$$

$$\frac{\partial L}{\partial F} = \left[A - 1\right] \left[1 - m\,(1 - e^{-gG})\right] \left[e^{-fF}\right] \left[-f\right] - \lambda\phi = 0 \quad (22)$$

$$\frac{\partial L}{\partial \lambda} = \overline{B} - \gamma G - \phi F = 0 \quad (23)$$

Solving (21), (22), and (23) as a set of simultaneous equations yields

$$G = \ln \left[\frac{m\,(\phi g - \gamma f)}{\gamma f\,(1 - m)}\right]^{\frac{1}{g}} \quad \text{and} \quad (24)$$

$$F = \frac{\overline{B}}{\phi} - \ln \left[\frac{m}{\gamma f} \frac{(\phi g - \gamma f)}{(1 - m)}\right]^{\frac{\gamma}{\phi g}} \quad (25)$$

Expressions (24) and (25) constitute the solution to (19), and substituting them into the effectiveness production function, (16), yields

$$\overline{E} = 1 + \left[A - 1\right] \left[\frac{\phi g(1-m)}{\phi g - \gamma f}\right] \left[\frac{m(\phi g - \gamma f)}{\gamma f(1-m)}\right]^{\frac{\gamma f}{\phi g}} \left[e^{\frac{-f\overline{B}}{\phi}}\right]. \quad (26)$$

Remember that the regression or other analysis used to select (16) provided numerical estimates for the parameters A, g, t, f, and m; also remember that $\overline{B}$, γ, τ, ϕ, and K are known.

Going on to the second step, the problem to solve is

$$\text{MAX} \quad E = 1 + \left[A - 1\right] \left[1 - m\,(1 - e^{-gG})\right] \left[1 - m\,(1 - e^{-tT})\right] \left[e^{-fF}\right]$$

$$\text{given} \quad \overline{B} = \gamma G + \tau T + K + \phi F \quad (27)$$

$$G,\ T,\ F \geq 0.$$

Proceeding similarly as in the first step, the solution to (27) is

$$
\begin{aligned}
G &= \ln \left[\frac{m(\phi g-\gamma f)}{\gamma f(1-m)}\right]^{\frac{1}{g}} \\
T &= \ln \left[\frac{m(\phi t-\tau f)}{\tau f(1-m)}\right]^{\frac{1}{t}} \\
F &= \frac{\overline{B}-K}{\phi} - \ln \left[\frac{m(\phi g-\gamma f)}{\gamma f(1-m)}\right]^{\frac{\gamma}{\phi g}} - \ln \left[\frac{m(\phi t-\tau f)}{\tau f(1-m)}\right]^{\frac{\tau}{\phi t}} ,
\end{aligned}
\tag{28}
$$

which upon substitution into (16) yields

$$
\hat{E} = 1 + \left[A - 1\right] \left[\frac{\phi g(1-m)}{\phi g - \gamma f}\right] \left[\frac{m(\phi g-\gamma f)}{\gamma f(1-m)}\right]^{\frac{\gamma f}{\phi g}} \left[\frac{\phi t(1-m)}{\phi t - \tau f}\right] \left[\frac{m(\phi t-\tau f)}{\tau f(1-m)}\right]^{\frac{\gamma f}{\phi t}} \left[e^{-f\frac{\overline{B}-K}{\phi}}\right] \tag{29}
$$

Step three involves the problem:

$$
\begin{aligned}
&\text{MIN} \quad B = \gamma G + \tau T + K + \phi F \\
&\text{given} \quad \overline{E} = 1 + \left[A - 1\right] \left[1 - m\,(1 - e^{-gG})\right] \left[1 - m\,(1 - e^{-tT})\right] \left[e^{-fF}\right] \\
&G,\ T,\ F \geq 0.
\end{aligned}
\tag{30}
$$

Here the relevant Lagrangian expression is

$$
L = \gamma C + \tau T + K + \phi G + \lambda \left[\overline{E} - 1 - \left[A - 1\right]\left[1 - m\,(1 - e^{-gG})\right] \left[1 - m\,(1 - e^{-tT})\right]\left[e^{-fF}\right]\right] . \tag{31}
$$

Here, as in the first and second steps, taking the partial derivatives of L with respect to G, T, F, and λ and setting the partials equal to zero gives the first order conditions

$$
\begin{aligned}
\frac{\partial L}{\partial G} &= \gamma + \lambda \left[A - 1\right]\left[1 - m\,(1 - e^{-tT})\right] \left[e^{-fF}\right] \left[gme^{-gG}\right] = 0 \\
\frac{\partial L}{\partial T} &= \tau + \lambda \left[A - 1\right]\left[1 - m\,(1 - e^{-gG})\right] \left[e^{-fF}\right] \left[tme^{-tT}\right] = 0 \\
\frac{\partial L}{\partial F} &= \phi + \lambda \left[A - 1\right]\left[1 - m\,(1 - e^{-gG})\right] \left[1 - m\,(1 - e^{-tT})\right] \left[fe^{-fF}\right] = 0 \\
\frac{\partial L}{\partial \lambda} &= \overline{E} - 1 - \left[A - 1\right]\left[1 - m(1 - e^{-gG})\right]\left[1 - m\,(1 - e^{-tT})\right]\left[e^{-fF}\right] = 0 .
\end{aligned}
\tag{32}
$$

Solving (32) as a set of simultaneous equations yields

$$
\begin{aligned}
G &= \ln \left[\frac{m(\phi g-\gamma f)}{\gamma f(1-m)}\right]^{\frac{1}{g}} \\
T &= \ln \left[\frac{m(\phi t-\tau f)}{\tau f(1-m)}\right]^{\frac{1}{t}} \\
F &= \frac{\bar{B}}{\phi} - \ln \left[\frac{m(\phi g-\gamma f)}{\gamma f(1-m)}\right]^{\frac{\gamma}{\phi g}} - \ln \left[\frac{m(\phi t-\tau f)}{\tau f(1-m)}\right]^{\frac{\tau}{\phi}},
\end{aligned}
\tag{33}
$$

and substituting (33) into (17) gives

$$
B = \bar{B} + K + \ln \left[\frac{m(\phi t-\tau f)}{\tau f(1-m)}\right]^{\frac{\tau}{t}} - \ln \left[\frac{\phi t-\tau f}{\phi t(1-m)}\right]^{\frac{\phi}{f}} . \tag{34}
$$

As the last step, the fourth requires solving the problem

$$
\begin{aligned}
&\text{MIN } B = \gamma G + \tau T + K + \phi F \\
&\text{given } \hat{E} = 1 + \left[A - 1\right] \left[1 - m\,(1 - e^{-gG})\right] \left[1 - m\,(1 - e^{-tT})\right] \left[e^{-fF}\right] \\
&\qquad T = 0 \\
&\quad G, F \geq 0.
\end{aligned}
\tag{35}
$$

The solution is

$$
\begin{aligned}
G &= \ln \left[\frac{m(\phi g-\gamma f)}{\gamma f(1-m)}\right]^{\frac{1}{g}} \\
F &= \frac{\bar{B}-K}{\phi} - \ln \left[\frac{m(\phi g-\gamma f)}{\gamma f(1-m)}\right]^{\frac{\gamma}{\phi g}} - \ln \left[\frac{m(\phi t-\tau f)}{\tau f(1-m)}\right]^{\frac{\tau}{\phi t}} + \ln \left[\frac{\phi t-\tau f}{\phi t(1-m)}\right]^{\frac{1}{f}}
\end{aligned}
\tag{36}
$$

and therefore

$$
\hat{B} = \bar{B} - K + \ln \left[\frac{\phi t-\tau f}{\phi t(1-m)}\right]^{\frac{\phi}{f}} - \ln \left[\frac{m(\phi t-\tau f)}{\tau f(1-m)}\right]^{\frac{\tau}{t}} . \tag{37}
$$

Now, using (34) the compensating budget variation, $C(T) = \bar{B} - \breve{B}$, is

$$
\ln \left[\frac{\phi t-\tau f}{\phi t(1-m)}\right]^{\frac{\phi}{f}} - \ln \left[\frac{m(\phi t-\tau f)}{\tau f(1-m)}\right]^{\frac{\tau}{t}} - K; \tag{38}
$$

and using (37) the equivalent budget variation, $E(T) = \hat{B} - \bar{B}$ is

$$
\ln \left[\frac{\phi t-\tau f}{\phi t(1-m)}\right]^{\frac{\phi}{f}} - \ln \left[\frac{m(\phi t-\tau f)}{\tau f(1-m)}\right]^{\frac{\tau}{t}} - K. \tag{39}
$$

Two points relative to (38) and (39) are noteworthy:

- C(T) and E(T) are determined entirely by the known (estimated) parameters f, t, m, K, τ, and ϕ.
- C(T) and E(T), in this example, are equal. This is not always necessarily so.

PRESENT VALUE ANALYSES

An important part of a TEC CTEA is the aggregation of TEC costs and benefits over time, step four of the methodology. That is, an intertemporal aggregation methodology must be a component of a TEC CTEA methodology. Intertemporal aggregation permits a series of annual costs and benefits to be distilled to the single number which is the sought measure of the value of TEC. While there exist a large number of aggregation schemes, most are variants of the following four well recognized approaches.

- Payback Period. The investment is judged worthwhile if it generates enough cost savings to pay back the initial cost of the investment within some given maximum period of time, e.g., five years.

- Benefit Cost Ratio. The investment is deemed worthwhile if the ratio of the present value of benefits to the present value of costs equals or exceeds unity.

- Internal Rate of Return. The investment is accepted as worthwhile if its rate of return equals or exceeds some predetermined hurdle rate.

- Net Present Value. The investment is determined to be worthwhile if the algebraic sum of the discounted costs and benefits exceeds zero. Table 1 presents a more formal comparison of these approaches.

Interestingly, while each of these measures of investment worth performs the requisite intertemporal aggregation, each results in a single number of different dimensions, and a different accept/reject criterion. Today, Net Present Value is generally regarded as the best approach to intertemporal aggregation. This is because the Payback Period approach ignores all costs and benefits beyond the period required to recover initial costs, and both the Benefit Cost Ratio and the Internal Rate of Return ignore the total size of the net benefits in favor of rate measures, i.e., dollars of benefits per dollar cost or dollar per year of benefits per dollars per year of costs.

Our goal in a CTEA is the development of methodology to evaluate specific training concepts or programs. The central element in the methodology is the determination of the value of the training program to a unit. This determination is accomplished using the concepts of compensating and/or equivalent budget variations. Of course, the methodology must consider <u>all</u> the elements which affect the "bottom line" value of the entire program, and tie all these considerations

Table 1

COMPARISON OF AGGREGATION METHODS

Aggregation Approach	Measure	Dimension of Measure	Criterion
Payback Period	Minimum Value of T which satisfies $\sum_{t=1}^{T} (B_t - C_t) \geq C_0$	years	$T \geq \overline{T}$, where $\overline{T}$ is the minimum acceptable pay-back period.
Benefit Cost Ratio	$R = \dfrac{\sum_{t=0}^{\infty} (B_t / (1+d)^t)}{\sum_{t=0}^{\infty} (C_t / (1+d)^t)}$	$\frac{\$}{\$}$	$R \geq 1$
Internal Rate of Return	Value of r which solves $C_0 = \sum_{1}^{\infty} \left[\dfrac{B_t - C_t}{(1+r)^t}\right]$	$\frac{\$/yr \text{ returned}}{\$/yr \text{ invested}}$	$r \geq d$
Net Present Value	$NPV = \sum_{t=0}^{\infty} \left[\dfrac{B_t - C_t}{(1+d)^t}\right]$	\$	$NPV \geq 0$

NOTATION:
- B_t Dollar value of project benefits in year t
- C_t Dollar costs of project in year t (the table assumes the whole initial cost is at t = 0)
- d The discount rate

together to arrive at an ultimate dollar valuation of the program. The relevant elements include

D_t	the program development costs in year t
M_t	the program maintenance costs in year t
$V(T_*)_{\ell t}$	the value of the program to unit l in year t
H	the time horizon for the program, i.e., t = 0, 1, 2, ..., H
d	the discount rate
L	the number of groups using the program, i.e., l = 1 ..., L
$NPV(T_*)$	net present value of the training program

The value of the program can be determined using an extension of the Net Present Value expression in Table 1. The Net Present VAlue of the training program is computed as

$$NPV(T_*) = \sum_{t=0}^{H} \left[\frac{D_t + M_t + \sum_{\ell = 1}^{L} V(T_*)_{\ell t}}{(1 + d)^t} \right]$$

By conventional standards, a program is deemed worthwhile if NPV ≥ 0; and not worthwhile otherwise.

With regard to the variables in ( ), we might expect D_t to be high in the early years and taper off thereafter. We would expect the opposite for M_t and $V(T_*)_{\ell t}$. The selection of a discount rate can be a complex issue. However, there exist military guidelines and these should be considered. Presently, a value of 10% is suggested for d.

SUMMARY AND FURTHER CONSIDERATIONS

SUMMARY

This is the second report dealing with CTEA methodology directed at determining the relative value of TEC training to unit combat effectiveness. The initial document[18] reported on a review and evaluation of literature relevant to a TEC CTEA and should be viewed as an introduction and background to this report. As discussed in the preceding report, because of TEC's unique complementary role, it does not fit the usual training program mold; therefore, analytical techniques available in current literature are not completely suitable for a TEC evaluation. This report develops a TEC-specific evaluation methodology - a new approach to training evaluation. The approach adopted in the development of this CTEA methodology is an extension of a model and several concepts from economic theory. The model used here to guide the choice among various types of training and to assess the value of TEC is an extension of the microeconomic theory of the consumer. Basically, we substitute a training effectiveness production function for the traditional utility function, where the former has much the same mathematical structure as the latter. The key concepts employed here in developing dollar values for the TEC program are the compensatory budget variation and the equivalent budget variation. These concepts are central to theoretical welfare economics, where they provide measures of the welfare effects of price changes on consumers. We extend these concepts to provide dollar measures of the value of training programs. The TEC CTEA methodology can be used to provide an objective economic evaluation of the contribution TEC training makes to unit performance. The methodology involves four steps:

- Specification and estimation of an Effectiveness Production Function.
- Estimation of the "per unit" costs of the different types of training contributing to overall effectiveness, as well as determination of the magnitude of the training budget.
- Calculation of the current value of the TEC Program.
- Calculation of the present value of the TEC Program.

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[18] Sassone, Literature Review - Cost and Training Effectiveness.

Each of these steps involves a number of substeps. The four steps are discussed in the second section.

FURTHER CONSIDERATIONS

This report presented a new approach to training evaluation; however, at this point, it is appropriate to point out some problems which remain to be solved before the methodology can be called complete, and before it can be implemented in a step-by-step, if not mechanical, fashion. Unfortunately, the remaining problems are essentially empirical, and can be resolved only by collecting and experimenting with actual data. These are three related areas of concern.

- Units of Observation.

  The methodology is compatible with units of any size, from individuals, squads, and platoons to entire battalions. However, different choices imply different data requirements, different data availability and quality, and different aggregation schemes. In the same vein, the methodology is compatible with units of different types, e.g. rifle squads, tank crews, artillery sections, etc., where the observational units might be grouped accordingly. The time period covered by a single observation is also open to choice. Observations might refer to a month, 3 months, year, etc. In all these choices, theory is of little value as a guide. Quite simply, the question is which approach works best.

- Inference.

  Very likely it will be neither possible nor desirable to gather data on all instances of TEC usage. It follows that the required estimate must be constructed using some type of inferential procedure.

o Size of the Data Set.

The number of variables, and the number of observations of each variable depend on, _inter alii_, the variances and invariances in the data. Clearly, only experience with actual data will reveal these statistics.

The importance of the foregoing issues should not be minimized. While none of the problems are insurmountable, their substantial resolution is a prerequisite to a complete CTEA methodology. And as already stressed, their resolution depends on the collection of and experimentation with actual data.